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Climate Change Implications on the Rangelands Condition in West Guji and Borana Zones, Southern Ethiopia

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Abstract:

Climate change is one of the most serious threats to rangeland. The implications of climate change on the rangelands conditions of the Duda and Gomole in Southern Ethiopia were examined. Measurements of rangeland were made using field survey and focus group discussions. Descriptive statistics, one way ANOVA was employed to detect whether a significant difference exists between range conditions while Pearson bivariate correlation was used to test the relationships between climate factors and herbaceous plants. The Mann−Kendall test was used to determine the trends of rainfall and temperatures over times; meanwhile Sen's slope estimator was used to test the magnitude of changes. The results showed no significant annual rainfall trend in both Duda and Gomole rangelands despite a slight increase in rainfall. However, the annual minimum temperature significantly increases in Duda rangeland while the annual maximum temperature significantly decreases in Gomole rangeland. The major herbaceous species in Duda rangeland (*Cenchrus ciliaris, Cynodon dactylon, Digitaria naghellensi, Digitaria milanjiana and Panicum maximum*) had a positive correlation with annual rainfall and a negative correlation with minimum temperatures. In the Gomole rangeland, *Cenchrus ciliaris* and *Bothriochloa insculpta* were negatively correlated with minimum temperature. The Duda rangeland was in poor condition where that of Gomole was in fair condition. This difference was mainly due to slight difference between climate of Duda (arid and semi-arid) and Gomole (arid) of the rangelands. The multiple linear regression showed that changes in rainfall and temperature accounted for 46% of variability on Duda rangeland condition whereas rainfall changes accounted for 32% of variability on Gomole rangeland condition. Therefore, the present study suggests rangeland rehabilitation in the short run through soil and water conservation, bush clearing and burning, and the planting of desirable grass species are critical to reduce the effects of climate change on rangeland.

Keywords: Climate Change; Rangeland Condition; Herbaceous Plant; Southern Ethiopia

1. Introduction

Rangelands are lands characterized by primarily grasses, grass-like plants, forbs, and shrubs as native flora (Joshi et al., 2004). Rangelands cover more than 40% of the earth's geographical area including 43% of Africa (Kassahun et al., 2008) and 62% of Ethiopia (Dalle et al., 2006a; Hoffman and Vogel, 2008). Millions of pastoral and agro-pastoral communities rely on rangelands for food and economic survival (Godde et al., 2019). Rangelands provide livelihoods for approximately 27% of Ethiopians (Kassahun et al., 2008). However, climate change, fire, and land-use con-

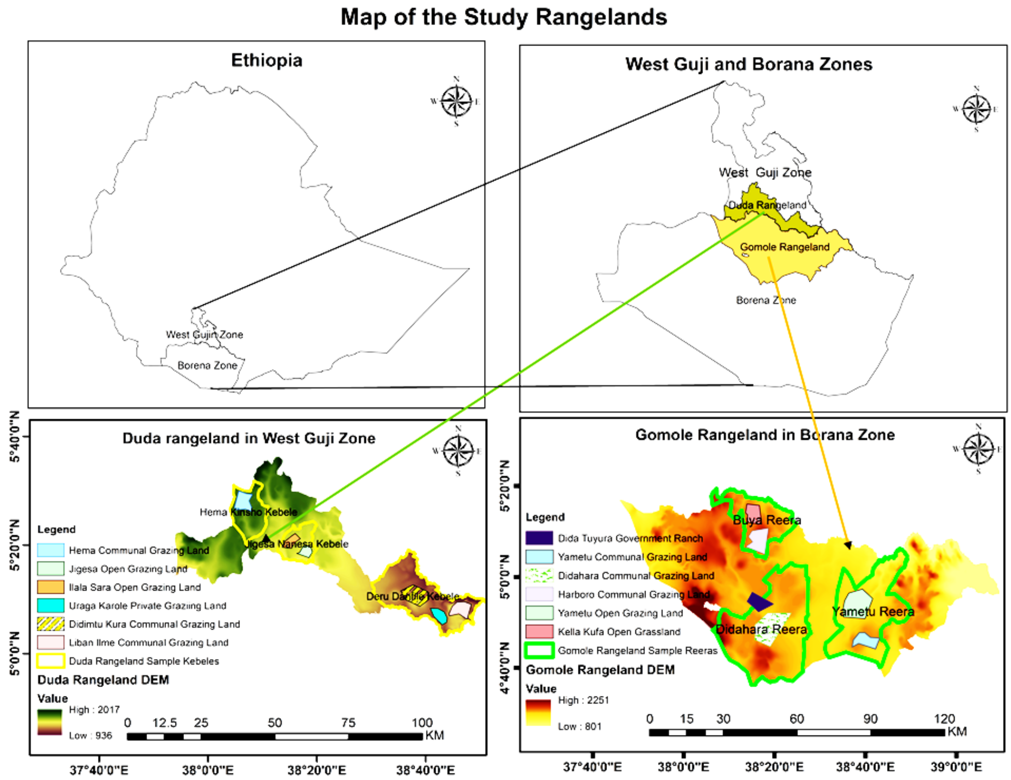

Figure 1. Location map of the study rangelands.

version all have global impacts on rangeland (Naidoo et al., 2013). As a result, rangeland ecosystems are changing at an unprecedented rate, as evidenced by the propagation of woody plants and the modification of herbaceous species (Naidoo et al., 2013; Zerga, 2015). Furthermore, climate change is visible in the rangeland environment as rising temperatures and changes in precipitation pose challenges to biodiversity and people's livelihoods (Ericksen et al., 2011). Rising temperatures, for example, appear to be reducing rangeland ecosystems' potential to retain water for plant growth (Kariuki et al., 2009). As a result, changes in vegetation cover have undoubtedly been observed. It accelerates the replacement of herbaceous vegetation with woodlands in the world's warm rangelands (Mckeon et al., 2009; Herrero et al., 2016; Briske, 2017; Hudson et al., 2019).

The sub-Saharan African rangelands, which include the East African rangelands, are really hard hit by the increasing water scarcity as a result of climate change (Ericksen et al., 2011). Moreover, changes in vegetation distribution in rangelands may be a cause of further change and have primarily become a driver for runoff in grazing lands, soil condition decline, and thus range condition deterioration (Ericksen et al., 2011; Briske, 2017). Furthermore, in arid and semiarid rangelands, rising human and livestock populations have significantly exacerbated rangeland condition deterioration through land use conversion caused by settlement expansions and overgrazing of grazing lands, resulting in a lack of fodder availability for livestock production and, ultimately, the pastoral livelihood failure (Yilma et al., 2009; Briske, 2017; Fereja, 2017).

Although numerous studies have been conducted in southern Ethiopian rangelands to assess rangeland conditions, vegetation distribution, and the effects of rangeland management strategies and physical environment on rangeland conditions (Oba et al., 2000a; Oba et al., 2000b; Angassa et al., 2006; Dalle et al., 2006a). There has not yet been a study that specifically addresses the implications of climate change on the rangeland condition of Southern Ethiopia. This study was conducted to better examine the implication of climate change on the Duda and Gomole rangeland conditions in the West Guji and Borana zones of southern Ethiopia. Specifically, it was attempted to analyze the association between the rangeland climate and herbaceous plant, and the implications of climate change on rangeland conditions.

2. Materials and Methods

2.1 Study area

The research was conducted in the rangelands of the West Guji and Borana zones in southern Ethiopia. The geographic locations of the West Guji zonal areas are found between 5°5′ N to 5°74′ N and 37°8′ E to 38°8′ E. The west Guji zone has a total land area of 18,577 km^2 with altitude varies between 700 and 3500m. The Borana zonal stretches from 3°51′ N to 5°32′ N and 36°6′ E to 39°74′ E, with a total land area of 95,000 km^2 and altitude varies between 750 and 2000m (Coppock, 1994; Dalle et al., 2006b). The first sample rangeland is the Duda rangeland of West Guji zone, is found in 5°5′ and 5°29′ N and 37°90′ and 38°50′ E with its altitude varies between 936 and 2017m. The Gomole rangeland of the Borana zone, is the second sample rangeland, and is situated between 3°97′ and 5°8′ N and

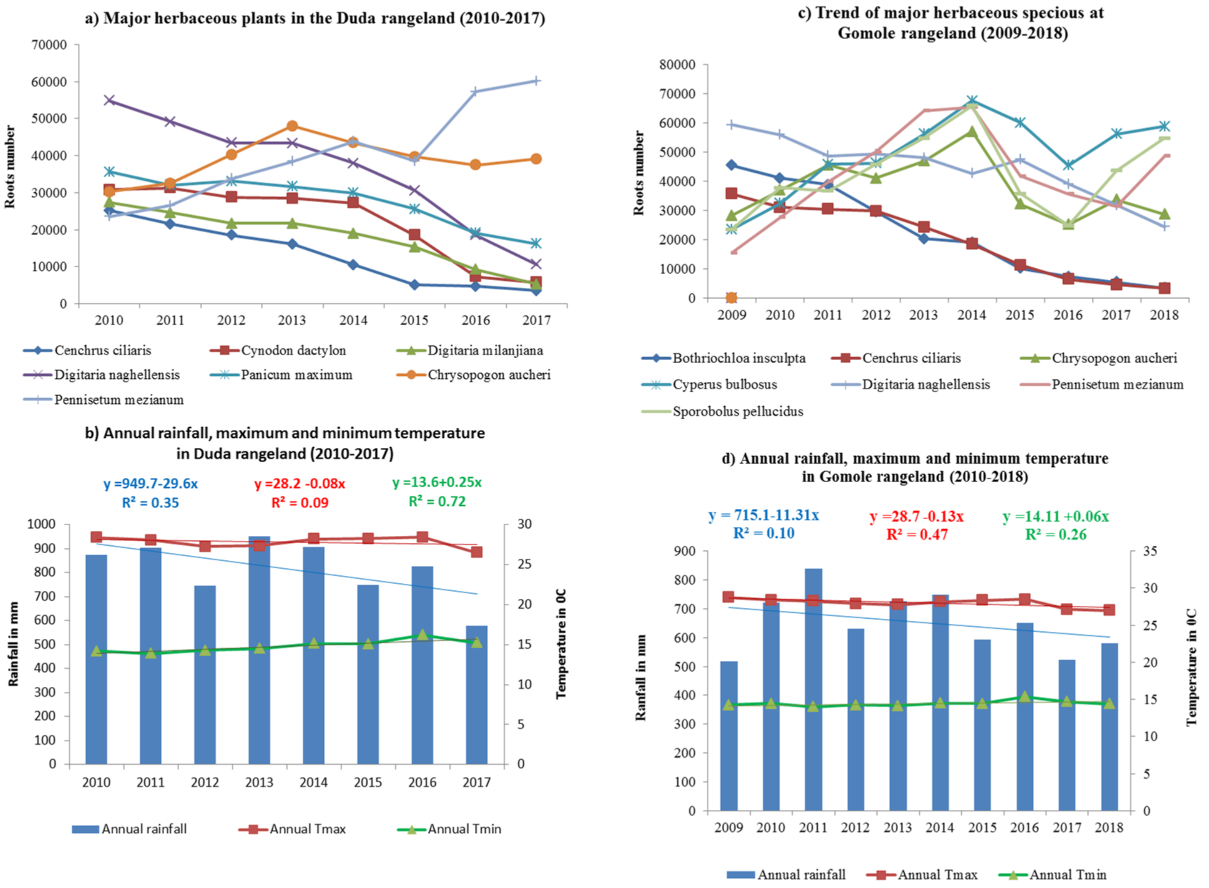

Figure 2. Herbaceous plants presentation alongside climate elements in the study rangelands.

37°80′ and 39°90′ E with altitude varies between 801 and 2251m (Fig 1).

The topographies of the study rangelands are plain land escapes with a volcanic cones, and depressions (Dalle et al., 2006b). The study rangelands have four major soil types: red soil (Biyye Diimma/Wayama), black soil (Koticha), white or gray soil (Biyye Adii), and sandy soil (Mansaa), which account for the majority of the soil types in Southern Ethiopia (Coppock, 1994; Angassa and Baars, 2000; Tolera and Abebe, 2007). The rangelands of Southern Ethiopia are primarily covered by grasslands, perennial herbaceous vegetation, and woody vegetation (Homann, 2004). In general, four major vegetation types characterize the vegetation of rangelands in Southern Ethiopia:

1. Evergreen and semi-evergreen bush land and thickets,
2. Acacia and Commiphora trees,
3. Shrubby Acacia, Commiphora, and allied genera, and
4. dwarf shrub grassland or shrub grassland (Angassa, 2005; Dalle et al., 2006a).

The climate of southern Ethiopian rangelands is arid and semiarid, with isolated pocket areas experienced sub-humid climate (Coppock, 1994; Oba and Kotile, 2001). The average annual temperature in the West Guji rangelands is between 24 and 29 °C, while the average annual temperature in the Borana rangelands is between 27 and 29 °C (Homann, 2004). The maximum temperature in the Duda rangeland ranges between 26.5 and 29.6 °C, while the maximum temperature at the Gomole rangeland varies between 26.9 and 29.4 °C. The minimum temperature in the Duda rangeland, on the other hand, varies between 13.9 and 16.2 °C, while it ranges between 13.9 and 16.3 °C in the Gomole rangeland. Furthermore, the annual rainfall in the Borana rangelands ranges from 400 to 700 mm, while the mean annual rainfall in the West Guji rangelands ranges from 550 to 700 mm (Berhanu, 2019). The annual rainfall in the Duda rangeland ranges between 600 and 700 mm, while annual rainfall in the Gomole rangeland ranges between 400 and 650 mm. In general, the rainfall pattern in Southern Ethiopian rangelands is bimodal, with 1) long rainy season or spring rainfall (Bokkeya Ganna) incorporating rainfall from the months of March, April, and May, and 2) short rainy season or autumn rainfall (Bokkeya Hageyya) incorporating rainfall from the months of September, October, and November (Dejene, 2020).

2.2 Sampling Method

West Guji and Borana zones were purposely chosen for this study, because comprehensive research on the implications of climate change on rangeland condition has not been conducted. So that, the Duda rangeland was chosen out of 4 west Guji zonal rangelands (Duda, Dawa, Cari and Galana rangelands) and the Gomole rangeland was selected out of five Borana zonal rangelands (Gomole, Wayama, Malbe,

Table 1. Trend of seasonal and annual rainfall and magnitude of change (1981–2018) in the Duda and Gomole rangelands.

Study areas	**Mann-Kendall trend (Z test)**			**Sen's Slope (Q)**		
	Spring	Autumn	Annual	Spring	Autumn	Annual
Duda rangeland	-0.25**	1.13	0.68	-0.24**	0.62	1.70
Gomole rangeland	0.20	2.61	2.19	0.08	0.99	4.10

** = Significant at 0.01

Table 2. Trend of mean maximum, minimum and annual temperature and magnitude of change (1981–2018) in the Duda and Gomole rangelands.

Study areas	**Mann-Kendall trend test (Z)**			**Sen's Slope (Q)**		
	T_{max}	T_{min}	MAT	T_{max}	T_{min}	MAT
Duda rangeland	-2.0	1.0	-1.2	-0.021	0.008	-0.008
Gomole rangeland	-0.8	1.8	-0.5	-0.009	0.007	-0.003

T_{max} = Annual maximum temperature,
T_{min} = Annual minimum temperature,
MAT = Mean annual temperature.

Dire, and Golbo rangelands). The selections of grazing lands were through Kebeles[1] and Reeras[2], were categorized into different grazing land management systems by the researchers. The grazing lands in the Duda rangeland's sampled Kebeles were classified into three management systems: communal, private, and open grazing lands. Similarly, total grazing lands in the Gomole rangeland's sampled Reeras were classified as communal, open, or Government Ranch. According to the study, the communal grazing land is thorny bush land that has been set aside for livestock grazing during the dry season. Private grazing land is owned by every family or household and is not subject to any resource utilization rules or regulations. Open grazing land is public land that is continuously grazed throughout the year, with no time for the grass species to recover from livestock grazing. The Government Ranches are government-owned grazing lands that are primarily used for livestock fattening, and dairy farming and are subject to stringent formal rules and regulations governing natural resource utilization. Therefore, three communal grazing lands (Dididimtu Kura, Liban Ilme, and Hema), one private (Urag Karole), and two open (Ilala Sara and Jigesa) were purposely selected from Duda rangeland. On the other hand, three communal grazing lands (Yametu Golba, Harboro, and Didahara), two open grazing lands (Kella Kufa and Yametu), and one government ranch (Dida Tuyura Ranch) were purposely selected from the total grazing lands (communal, open, and Government Ranch) in Gomole rangeland.

Prior to range condition data collection from the field, transects were randomly placed in each sample grazing land. Two 400 m transect lines (2×400m = 800m) were placed in each grazing land. A total of 6–7 km transects were laid randomly in six grazing lands with different management systems in three sample Kebeles and Reeras in the Duda and Gomole rangelands, From each grazing land, ten 400 m^2 (20×20m) sample plots were chosen randomly from the Duda and Gomole rangelands. The range condition factors were evaluated in a nested plot of 1 m^2 (1×1m).

1. Kebele is the Ethiopia's smallest government administrative unit.
2. Reera is the smallest customary administrative unit in the Borana rangelands of southern Ethiopia.

2.3 Participant selection for focus group discussion (FGD)

FGD participants were sought to identify trends of range condition, herbaceous and bush species in the grazing lands of various management systems in the study rangelands. Thus, five participants were chosen purposely from one grazing land users in the Kebele of the Duda rangeland and five participants were also picked from one grazing land users in the Reera of the Gomole rangeland. A total of 45 peoples were chosen from three grazing lands in three Kebeles of the Duda rangeland (e.g., 5 peoples × 3 grazing lands × 3 Kebeles = 45 peoples). Similarly, 45 peoples were chosen from 3 grazing lands in 3 Reeras in the Gomole rangeland (e.g., 5 peoples × 3 grazing lands × 3 Reeras = 45 peoples).

2.4 Data collection

2.4.1 Climate data

Ethiopia's National Meteorological Agency (NMA) has provided merged station-satellite climate data (monthly minimum and maximum temperatures, as well as monthly rainfall) for the Kebeles of Duda and Reeras of Gomole rangelands for the past 38 years (1981–2018). Experts from the national meteorological agency evaluated the data's quality. Data for the Duda and Gomole rangelands were downloaded at 4.16×4.16 km intervals with a grid cell size of 0.0375 degrees.

2.4.2 Range condition factors data

Rangeland condition data were collected at the end of the long rainy season, which lasted from early June to the end of August 2021. This time period was chosen for data collection because most grass species were expected to be in blooming stage. The assessment was carried out across

Table 3. Correlation between climate and major herbaceous plants at Duda rangeland (2010–2017) and Gomole rangeland (2009–2018).

Herbaceous plants	Duda rangeland (2010–2017)			Herbaceous plants	Gomole rangeland (2009–2018)		
	Rainfall	T_{max}	T_{min}		Rainfall	T_{max}	T_{min}
Cenchrus ciliaris	0.56	0.18	-0.86**	*Cenchrus ciliaris*	0.37	0.57	-0.65*
Chrysopogon aucheri	0.08	-0.39	-0.39	*Chrysopogon aucheri*	0.70*	0.02	-0.47
Digitaria naghellensis	0.70*	0.36	-0.82*	*Digitaria naghellensis*	0.25	0.81*	-0.38
Pennisetum mezianum	-0.54	-0.36	0.86**	*Pennisetum mezianum*	0.46	-0.35	-0.20
Cynodon dactylon	0.69*	0.25	-0.83**	*Bothriochloa insculpta*	0.33	0.66*	-0.54
Digitaria milanjiana	0.70*	0.36	-0.77*	*Cyperus bulbosus*	0.14	-0.55	0.06
Panicum maximum	0.67*	0.30	-0.80*	*Sporobolus pellucidus*	0.28	-0.58	-0.30

T_{max} = Annual maximum temperature,
T_{min} = Annual minimum temperature,
*, ** = The correlation coefficients are significant at the 0.05 and 0.01 probability levels, respectively.

rangeland grazing lands, following the paths of Angassa and Dalle (Angassa et al., 2006; Dalle et al., 2006a). Grazing lands were sampled for assessment of range condition factors such as grass species botanical composition, basal cover, litter cover, number of seedlings, age distribution, soil erosion, and soil compaction. In the Duda rangeland, for example, data were collected from grazing lands of communal, private, and open. Similarly to the Gomole rangeland, the required information was gathered from communal, open and Government Ranch grazing lands. Thus, the grass composition, basal cover, and litter cover were rated from 0 to 10, whereas grass seedlings, age distribution, soil erosion, and compaction were rated from 0 to 5 (Dalle et al., 2006a). The following rangeland condition ratings were implemented: very poor (10 points), poor (11–20 points), fair (21–30 points), good (31–40 points), and excellent (41–50 points) (Angassa et al., 2006). A total rangeland condition score was obtained from sum values of seven condition factors: Plant composition, basal cover, and litter cover, number of seedlings, age distribution, soil erosion and soil compaction.

2.4.3 Focus group discussion (FGD) data

FGD was used to collect community perception about trends in range condition factors as well as trends in herbaceous and bush species. Three focus groups were conducted separately with users of similar grazing land. Thus, 15 people took part in one FGD in the Duda or Gomole rangelands. In general, three separate FGDs were conducted in the Duda rangeland with users of communal, private, and open grazing lands, as well as three separate FGDs in the Gomole rangeland with users of communal, open, and Government Ranch grazing lands.

2.4.4 Secondary data

The second hand herbaceous plant data for Duda rangeland between 2010 and 2017 was obtained from the Agriculture and Natural Resource office of Dugda Dawa district in West Guji. Similarly, herbaceous plant data of Gomole rangeland from 2009 to 2018 was obtained from the Agriculture and Natural Resource office of Gomole district in Borana Zone.

2.5 Data analysis

2.5.1 Mann-Kendall trend and Sen's slope

Mann-Kendall trend test and Sen's slope non parametric test tools were used to estimate the trend of temperature and rainfall for the study areas over the last 38 years (1981-2018), whereas Sen's slope estimator was used to estimate the magnitude of temperature and rainfall trend or change (Ayal et al., 2018).

Equations 1 and 2 represents the Mann-Kendall trend test:

$$S = \sum_{i-1}^{N-1} \frac{\sum_{j-i+1}^{N} \text{sign}\,(X_j - X_i)}{\sigma}, \tag{1}$$

$$\sigma = \sqrt{\frac{1}{18}\left(N(N-1)(2N+5) - \sum_{i-1}^{n} t_i(t_i-1)(2t_i+5)\right)}. \tag{2}$$

Where S is the Mann-Kendall trend test statistic, x_i and x_j are the season/annual time series sequential data values with $j > i$, N is the time series length, and $\text{sign}(x_j - x_i)$ is defined as below (**Eshetu2018**),

$$\text{sign}(x_j - x_i) = \begin{cases} 1 & x_j - x_i > 0, \\ 0 & x_j = x_i, \\ -1 & x_j - x_i < 0. \end{cases}$$

As a result, if the p-values are greater than the significant level, there is a statistically significant trend vice versa.

Sen's slope estimator was used to test the slope of the trend. Equation 3 represents Sen's slope estimator mathematically.

$$\text{Sen's Slope} = \text{median}\left\{\frac{x_i - x_j}{i - j} \mid i < j\right\}, \tag{3}$$

Where x_i and x_j are the values of the variable at time steps i and j, respectively.

A value close to zero indicates that there is no change in slope. A negative slope value represents the strength of a negative trend, while A positive slope value represents the strength of a positive trend.

Table 4. Herbaceous species desirability (forage value) for livestock production.

Botanical name	Duda Rangeland	Gomole Rangeland
Andropogon chinensis	Highly desirable	Least desirable
Aristida kenyensis	Intermediate	Intermediate
Barleria spinisepala	Least desirable	Highly desirable
Borhrichloa radicans	Not identified	Least desirable
Bothriochloa insculpta	Highly desirable	Highly desirable
Cenchrus ciliaris	Highly desirable	Highly desirable
Chloris roxburghiana	Not identified	Intermediate
Chlorophytum gallabatense	Highly desirable	Highly desirable
Chrysopogon aucheri	Intermediate	Highly desirable
Commelina africana	Intermediate	Highly desirable
Cynodon dactylon	Highly desirable	Highly desirable
Cyperus bulbosus	Intermediate	Least desirable
Cymbopogon commutatus	Intermediate	Intermediate
Cyperus sp	Intermediate	Intermediate
Dactyloctenium aegyptium	Least desirable	Highly desirable
Digitaria milanjiana	Highly desirable	Highly desirable
Digitaria naghellensis	Highly desirable	Highly desirable
Eleusine intermedia	Intermediate	Least desirable
Eragrostis capitulifera	Intermediate	Intermediate
Eragrostis papposa	Intermediate	Intermediate
Harpachne schimperi	Intermediate	Intermediate
Heteropogon contortus	Highly desirable	Least desirable
Indigofera volkensii	Not identified	Intermediate
Leptothrium senegalense	Intermediate	Intermediate
Loudetia flavida	Highly desirable	Intermediate
Melinis repens	Least desirable	Least desirable
Ozoroa insignis	Intermediate	Intermediate
Panicum maximum	Intermediate	Highly desirable
Pennisetum mezianum	Least desirable	Least desirable
Setaria verticillata	Highly desirable	Highly desirable
Sporobolus discosporus	Intermediate	Intermediate
Sporobolus pellucidus	Intermediate	Intermediate
Themeda triandra	Highly desirable	Intermediate

2.5.2 Inferential statistics

Analysis of variance (ANOVA) was used to test whether there was any significant difference in range conditions and factors among different grazing lands. Pearson bivariate correlation was used to test the level of association between climate and herbaceous plants.

Multiple linear regression method was used to estimate the effect of climate change on the rangelands conditions in Duda and Gomole. The dependent variable (rangeland condition) and independent variables (rainfall and temperature), Equation 4 denotes the model specification:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + e, \qquad (4)$$

Where Y is rangeland condition in 2021, B_0 is the constant, B_1, B_2, B_3, B_4 are regression coefficients, X_1 is the rate of annual rainfall change from 1981 to 2018, X_2 is the rate of seasonal rainfall from 1981 to 2018, X_3 is the rate annual mean temperature, and X_4 is the trend seasonal mean temperature.

Data were statistically analyzed using STATA V.14.1 and XLSTAT V.2020 software packages.

3. Results

3.1 Climate trend and magnitude of change

Spring total rainfall in the Duda rangeland decreases significantly by 0.24 mm per season ($P < 0.05$) over 38 years (1981–2018), while autumn and annual rainfall increases over 38 years, respectively (Table 1). However, in the Gomole rangeland, spring and autumn rainfall increase by 0.08 and 0.99 mm, respectively, while annual rainfall increases by 4.10 mm between 1981 and 2018 (Table 1).

From 1981 to 2018, mean annual maximum and mean annual temperatures decreased in both the Duda and Gomole rangelands. However, the mean annual minimum temperature rises by 0.008 and 0.007 °C, respectively, in Duda and Gomole rangelands, respectively (Table 2).

3.2 Herbaceous plants presentation alongside rainfall and temperature conditions

Long-term herbaceous vegetation survey reports compiled by the Agriculture and Natural Resource Office Rangeland department of Dugda Dawa district in West Guji Zone and Gomole district in Borana Zone revealed a trend of herbaceous species at the Duda and Gomole rangelands.

In the Duda rangeland (Fig. 2a), of all herbaceous species

Table 5. Mean range condition and factors of different grazing lands management systems.

Factors name (Scores)	Duda rangeland (Mean ± SD)				Gomole rangeland (Mean ± SD)			
	Communal	Private	Open	Mean	Communal	Open	Government	Mean
Grass composition	5.0±1.1	3.4±0.9	4.6±1.6	4.6	5.8±0.9	4.6±1.2	6.2±0.8	5.5
Grass basal cover	4.3±0.9	3.5±1.3	3.7±1.5	3.9	5.5±0.7	4.1±1.2	5.9±0.6	5.1
Litter cover	4.1±0.9	3.3±1.1	4.1±1.5	4.0	5.5±1.0	3.9±1.5	5.5±0.5	5.0
Grass seedlings No.	1.7±0.7	1.4±0.8	1.8±0.9	1.7	2.0±0.7	1.2±1.1	2.2±0.9	1.8
Grass age distribution	2.0±0.7	1.7±0.6	2.2±0.9	2.0	2.6±0.8	2.0±0.7	2.6±0.5	2.4
Soil erosion	2.2±0.6	1.7±0.9	1.6±0.8	1.9	2.7±0.7	2.1±0.8	2.6±0.4	2.5
Soil compaction	1.9±0.7	1.9±0.5	1.7±0.7	1.8	2.5±0.6	2.2±0.9	2.7±0.6	2.5
Range condition score	21.2±2.8	17.0±4.1	19.7±5.5	19.9	26.6±3.9	20.2±6.0	27.6±1.7	24.6
Rangeland condition class	Fair	Poor	Poor	Poor	Fair	Fair	Fair	Fair

identified by survey reports (*Cenchrus ciliaris, Chrysopogon aucheri, Cynodon dactylon, Digitaria milanjiana, Digitaria naghellensis and Panicum maximum*) except *Pennisetum mezianum* increased between 2010 and 2017 (Fig. 2a). In relation to these, the annual rainfall and maximum temperature decreases, while the minimum temperature increases significantly (R^2 = 0.72) between 2010 and 2017 in the Duda rangeland (Fig. 2b).

Furthermore, in the Gomole rangeland, out of the total herbaceous species (*Bothriochloa insculpta, Cenchrus ciliaris, Chrysopogon aucheri, Cyperus bulbosus, Digitaria naghellensis, Panicum maximum, Pennisetum mezianum, and Sporobolus pellucidus*), *Chrysopogon aucheri* increases, despite *Bothriochloa insculpta* and *Cenchrus ciliari* decrease between 2009 and 2018 years (Fig. 2c). Consistent with the finding, the maximum temperature significantly decreases (R^2 = 0.47) between 2009 and 2018 years in the Gomole rangeland (Fig. 2d).

To sum up, in Duda rangeland, the trends of herbaceous species (*Cenchrus ciliaris, Cynodon dactylon, Digitaria naghellensi, Digitaria milanjiana and Panicum maximum*) significantly decrease, except *Pennisetum mezianum* that increased between 2010 and 2017 years. The increase in *Pennisetum mezianum* was due to mainly less desirability of the species for livestock production (Table 4).

In the Gomole rangeland, the trends of highly desirable species (*Cenchrus ciliaris* and *Bothriochloa insculpta*) were significantly decreased, despite *Chrysopogon aucheri* significantly increases in the rangeland. The increase of *Chrysopogon aucheri* was due to intermediate desirability (increaser) for livestock production (Table 4).

3.3 Correlation between climate factors and herbaceous plants

The study found a positive correlation between annual rainfall and herbaceous plants like *Cynodon dactylon, Digitaria milanjiana, Panicum maximum* and *Digitaria naghellensis* ($P < 0.05$) in the Duda rangeland, indicating by increasing annual rainfall the frequency of plant species increased. For *Pennisetum mezianum* here was weak negative correlation between annual rainfalls in the same area. In the Gomole rangeland, there was positive correlation between *Chrysopogon aucheri*, with annual rainfall ($P < 0.05$) and its frequency significantly increased over time (Table 3).

In the Duda rangeland, there was no correlation between herbaceous plants with maximum temperature, whereas in the Gomole rangeland, *Digitaria naghellensis* and *Bothriochloa insculpta* had positive correlation with maximum temperature ($P < 0.05$), indicating their frequency were increased over times (Table 3).

In the Duda rangeland, there were strong negative correlations between the herbaceous plants such as *Cenchrus ciliaris, Digitaria naghellensis, Cynodon dactylon, Digitaria milanjiana* and *Panicum maximum* with minimum temperature ($P < 0.01$), indicating that by risen minimum temperature, the frequency of species were deceased (Table 3). In contrast there, was positive correlation between *Pennisetum mezianum* with minimum temperature ($P < 0.01$) indicating by risen minimum temperature, the frequency of this species was decreased (Table 3). In the Gomole rangeland, there were negative correlations between *Cenchrus ciliaris* with minimum temperature ($P < 0.05$), similar trend was observed for *Bothriochloa insculpta* indicating that by risen minimum temperature, the frequency of the two species were deceased (Table 3).

3.4 Range condition factors

For assessment of range condition, the collected data for grass botanical composition, basal cover, litter cover, number of seedlings, age distribution, soil erosion, and soil compaction in both reigns were as follows:

3.4.1 Grass composition

The study results revealed that 31 herbaceous species from the Duda rangeland and 33 herbaceous species from the Gomole rangeland were used as livestock fodder (Table 4). There was a significant variation regarding the grass composition among the grazing lands managed under different management systems in the Duda and Gomole rangelands ($P < 0.05$). For example, at the Duda rangeland, grass composition remained fair in communal grazing land (score 5.0), very poor at private (3.6), and open (4.6) grazing lands. Furthermore, one-way ANOVA result showed a significant difference in grass composition among communal, open, and private grazing lands in the Duda rangeland ($P < 0.05$). Similarly, the one way ANOVA result confirmed that there was a significant difference in the composition of grasses in

Table 6. Multiple linear regression ANOVA between climate data and rangeland condition in Duda and Gomole, regions, Southern Ethiopia.

Source	Duda rangeland				Source	Gomole rangeland			
	DF	SS	MS	F		DF	SS	MS	F
Regression	3	512.19	170.73	16.9**	Regression	2	560.67	280.33	13.44**
Residual	56	590.55	10.54		Residual	57	1188.59	20.85	
Total	59	1102.7	18.69		Total	59 1	749.26	29.64	

** = The regression models are significant at 0.01 probability levels.

Table 7. Multiple linear regression equations between climate data and rangeland condition in Duda and Gomole, regions, Southern Ethiopia.

Locations	Regression equation $Y = B_0 + B_1X_1 + B_1X_2 + \ldots$	R^2 values
Duda rangeland	Rangeland condition = 30.76 + 10.36 Annual rainfall + 7.99 Annual temp.	$R^2 = 0.46$
Gomole rangeland	Rangeland condition = 9.90 + 11.19 Annual rainfall + 8.29 Autmn rainfall	$R^2 = 0.32$

the Gomole rangeland's communal, open, and government ranch grazing lands ($P < 0.05$). The grass composition in the Duda rangeland was generally poor, whereas the composition in the Gomole rangeland was fair (Table 5).

3.4.2 Basal and litter cover

According to the result, communal grazing land in the Duda rangeland had poor basal and litter covers (scores of 4.3, 4.1), while private grazing land had poor basal and litter covers (3.5, 3.3), and open grazing land had also poor basal cover (3.7) and poor litter cover (4.1). However, the basal and litter covers in communal grazing land in Gomole rangeland were found fair (5.5, 5.5). Similarly, the basal and litter cover in the rangeland's government ranch were found to be fair (5.9, 5.5), whereas the basal and litter covers in the open grazing lands were poor (4.1) and very poor (3.9), respectively. Furthermore, one way ANOVA results show that there was no significant variation amongst the basal and litter covers in the Duda rangeland's communal, open, and private grazing land management systems, whereas there was a significant variation among basal and litter covers in the Gomole rangeland's amongst grazing land management systems ($P < 0.05$). Overall, grass litter and basal covers were found to be very poor and poor in the Duda rangeland, respectively, whereas grass litter and basal covers were found to be fair in the Gomole rangeland (Table 5).

3.4.3 Number of grass seedling

In the Duda rangeland, the average score of grass seedling in the communal (score 1.7), open (1.4), and private (1.8) grazing lands remained very poor, whereas grass seedlings in the Gomole rangeland's communal (2.0) and government ranch (2.2) grazing lands found poor as compared to the very poor grass seedling in open grazing lands (1.2). To summarize, there was no significant variation among number of grass seedlings in the grazing lands of different management systems in the Duda rangeland, but there was significant variation of number of grass seedlings in the grazing lands of management systems in the Gomole rangeland ($P < 0.05$). In general, the number of grass seedlings was very low in both the Duda and Gomole rangelands (Table 5).

3.4.4 Soil erosion and compaction

The study results show that in the Duda rangeland, communal grazing land has the lowest soil erosion (score 2.2), while private (1.7) and open (1.6) grazing lands have the highest soil erosion. Soil erosion was found to be lower in the communal (2.7) and Government Ranch (2.6) areas of the Gomole rangeland, while it seems medium in the open grazing land (2.1). Furthermore, in the Duda rangeland, soil compaction was highest in all grazing land management systems, including communal (1.9), private (1.7), and open (1.9) grazing lands, whereas in the Gomole rangeland, soil compaction was found to be medium in communal (2.5), open (2.2), and Government Ranch (2.7) grazing lands. In general, there was a significant difference in soil erosion manifestation in the Duda rangeland grazing land management systems ($P < 0.05$). Similarly, soil erosion in the Gomole rangeland varied significantly across grazing land management systems ($P < 0.05$). However, there was no significant variation in soil compaction among different grazing land management systems in both Duda and Gomole rangelands. Soil erosion was generally greater in the Duda rangeland compared to intermediate soil erosion in the Gomole rangeland (Table 5).

3.5 Overall rangeland condition

The range condition in the Duda rangeland's communal grazing land (21.2) was fair, but the condition in the rangeland's private and open grazing lands was poor (17.0, 19.7), whereas the range conditions of all types of grazing lands remained fair in the Gomole rangeland. Government Ranch (27.6) and communal (26.6) grazing lands were found to be slightly better than open grazing land. In the Duda rangeland, there was a significant difference in range conditions between communal, private, and open grazing lands ($P < 0.05$). Similarly, in the Gomole, there was a significant difference in range condition between communal, open, and Government Ranch grazing lands ($P < 0.05$) (Table 5). To summarize, the Duda rangeland was in poor condition, whereas the Gomole rangeland was in fair condition (Table 5).

3.6 Perceived rangeland condition trend

Pastoralists perceived that in the Duda rangeland climate change, in the form of recurrent drought, increased bush encroachment due to ban of fire was the major drivers of decreased desirable herbaceous species in communal grazing lands. Human and livestock population pressures, as well as associated grazing land overgrazing and crop cultivation expansion in rangelands, were identified as drivers of rangeland condition deterioration in the Duda rangeland's communal, private and open grazing lands.

The response from pastoralists FGD in the Gomole rangeland, on the other hand, showed that frequent drought incidences, bush encroachment, and overgrazing were the major drivers of decreased desirable herbaceous species. Likewise, the response showed that in the open and communal grazing lands, livestock population pressure, bush encroachment, and severe drought frequencies were the major causes of desirable herbaceous species change, whereas in the Government Ranch, bush encroachment, drought recurrence, and overgrazing were among the major drivers of desirable herbaceous species declining and disappearance. In general, the conditions of all grazing land systems in the rangelands have deteriorated as a result of climate change manifestations such as frequent drought and contaminant bush encroachment and herbaceous species change, and thereby water runoff and soil erosion in the grazing lands.

Furthermore, the FGD participants in the Duda rangeland revealed the most important remedial measures for their deteriorating rangeland condition. They indicated that biophysical measures or land conservation activities such as soil and water conservation, bush clearing and burning, and planting of desirable forage species in rangeland (i.e., *Cenchrus ciliaris*, *Digitaria milanjiana*, and *Digitaria naghellensis*) can be completed in a short period of time. Participants also indicated that improved rangeland conditions would be critical in managing the effects of climate change-induced water stress on vegetation growth and rangeland degradation problems. Furthermore, the problem of livestock forage scarcity could be addressed. Ultimately, livestock overgrazing was identified as a greater threat to rangeland sustainability by FGD participants in the Gomole rangeland, but it is primarily manageable through a shift in livestock species from grazers (i.e., cattle) to browsers (i.e., camel and goat).

3.7 Climate change implications on the conditions of the rangelands

Multiple linear regression model equation was used to estimate the effects of climate change on the conditions of the Duda and Gomole rangelands. The model results showed that the coefficient of determination ($R^2 = 0.46$) confirmed that 46% of the variability of Duda rangeland condition in 2021 was explained by trend of annual rainfall and trend of mean annual temperature of the rangeland (Table 6).

According to the results in Table 7, the result indicates that the trend of annual rainfall and trend of autumn rainfall accounted $R^2 = 32\%$ of the variability of the Gomole rangeland condition of the year 2021. Besides, the total annual rainfall increment in the Gomole rangeland accompanied with the rangeland condition improvement by 11.19, and 8.29 for annual and autumn rainfall, respectively (Table 7).

4. Discussion

Pastoralists reported that the historical vegetation distributions (trees, grasses, forbs, and shrubs) in the rangelands of Southern Ethiopia altered (Oba et al., 2000a). According to the study findings, highly desirable grass species (decreases) were lower in all grazing lands in the Duda and Gomole rangelands when compared to medium desirable species (increases). Accordingly, in the Duda rangeland the frequency of highly desirable grass species (*Cenchrus ciliaris, Cynodon dactylon, Digitaria milanjiana and Digitaria naghellensis*) decreased between 2010 and 2017 years, while in the Gomole rangeland, the frequency of *Bothriochloa insculpta* and *Cenchrus ciliaris* decreased between 2009 and 2018 years. According to (Dalle et al., 2006a), the most desirable herbaceous species (decreases) in the Borana rangelands of Southern Ethiopia were *Cenchrus ciliaris, Digitaria milanjiana, Digitaria naghellensis,* and *Dactyloctenium aegyptium*. (Angassa, 2002) disclosed that three palatable herbaceous species (*Cenchrus ciliaris, Bothriochloa radicans, and Chrysopogon aucheri*) were important forage species in Southern Ethiopia's Borana rangeland. However, the Borana rangeland has degraded and been overgrazed over time (Oba and Kotile, 2001; Oba et al., 2000a). Only *Chrysopogon aucheri* appeared to be the most dominant grass species in Borana rangelands (Dalle et al., 2006a). As a result, the declined highly desirable grasses in the rangeland could be indicator for Southern Ethiopia's deteriorating rangeland condition. Furthermore, the current study results confirm that the grass composition, basal and litter cover in the communal grazing lands of the Duda rangeland were better than in the open and private grazing lands, whereas the grass composition in the Government Ranch and communal grazing lands of the Gomole rangeland remained higher relative to the grass composition, basal and litter cover in the open grazing lands. In general, grass composition, basal and litter cover in the Duda rangeland ranged from poor to very poor, whereas grass composition, basal and litter cover in the Gomole rangeland were found to be in fair condition. Another study revealed that basal cover in open Borana rangelands was significantly higher than in encroached Borana rangelands (Angassa, 2002). The study revealed that basal and litter covers are critical for soil erosion control in grazing lands of the rangelands (Angassa and Baars, 2000).

The increased encroachment of bush species such as *Acacia drepanolobium* and Acacia brevispica associated with unpalatable grasses, primarily *Pennisetum mezianum* and *Panicum stramineum*, were the major drivers of range condition deterioration (Angassa and Beyene, 2003; Dalle et al., 2006a). Furthermore, climate change occurrence, such as drought frequency, can have the greatest impact on rangeland biodiversity dynamics (Zerga, 2015). According to

(Dalle et al., 2006b), the primary causes of range condition deterioration were drought frequency and livestock population pressure. In general, heavy bush encroachment has reduced herbaceous species availability, resulting in a critical feed shortage (Yilma et al., 2009). In this regard, the Borana elders identified bush encroachment, along with overgrazing, as a major cause of range deterioration (Angassa, 2005). Furthermore, it has been confirmed that drought-induced bush encroachment is one of the major causes of forage scarcity in southern Ethiopia, resulting in cattle mortality (Wako et al., 2017). The empirical evidences show that the mean vegetation cover of bush encroachment in the Borana rangelands increased from less than 40% in the early 1990s to more than 40% 1994 (Coppock, 1994) to 52% in 2002 (Dalle et al., 2006a), which was the primary driver of herbaceous species change in Southern Ethiopia's rangelands. Besides, high grazing pressure, and the fire ban were found to have a negative impact on range condition in terms of botanical composition, bush encroachment, soil erosion, and forage production (Angassa and Baars, 2000). In general, deteriorating range conditions has been identified as a major cause of livestock productivity decline in rangelands (Angassa and Beyene, 2003).

According to the study findings, annual rainfall was found to be very important for the improvement of the conditions of the Duda and Gomole rangelands, whereas autumn season rainfalls change were also significantly improve the conditions of the Gomole rangeland. However, the effects of mean annual temperature change on grazing lands of Duda rangeland were found to be significant relative to Gomole rangeland condition. The other study results show extreme precipitation events do occur in semiarid regions, which can transport large amounts of sediment, but the cover required to protect the soil from wind and water erosion is insufficient. Further, when grazing pressure is applied repeatedly during a drought, the risk of erosion increases (Thurow and Taylor, 1999). In contrast to the finding, increased temperatures are expected to increase evaporative demand and cause more overall water stress (McCollum et al., 2017). Furthermore, in Tanzania, rising temperatures and decreasing rainfall interact with grazing pressure and changing land cover to influence the composition of rangeland plants (Reeves et al., 2018; Mwakaje, 2013). The effect of climate change on rangelands is remarkable. In many cases, when some unpalatable bushes are seen, is a general indication of climate change impact rangelands (Yilma et al., 2009). Climate change, in general, has biophysical consequences for rangeland ecosystem (McCollum et al., 2017). From this perspective, the research findings from Asian rangelands revealed that overall rangeland vegetation cover decreased significantly when warming and drought frequency interacted (Kohli et al., 2020). Furthermore, pastoralists cited recurring drought as a major cause of range deterioration and unprecedented cattle deaths in Southern Ethiopia's Borana rangelands (Angassa and Beyene, 2003; Dalle et al., 2006a; Wako et al., 2017).

5. Conclusion

It is concluded that the climate of Southern Ethiopia's Duda and Gomole rangelands has changed over the last three decades (1981–2018). The trends of major herbaceous plants were identified parallel to the trend of climate in the study rangelands. There were positive correlations between the trend of major herbaceous plants, rainfall, and maximum temperature in both rangelands; however, there were negative correlations with minimum temperature. Pastoralists also mentioned the frequent droughts mostly brought on by erratic rainfalls, bush encroachment and livestock population pressures, the ban of burning grazing land and livestock overgrazing problems as contributing factors to the variability of range conditions under study. Therefore, we suggest that short-term improvements in rangeland conditions in southern Ethiopia should result from land conservation efforts like soil and water conservation projects and the planting of desirable grasses in grazing lands. As a result, the effects of climate change on rangeland herbaceous plants will be minimized. Pastoral livelihoods based on livestock production will be threatened in the near future if nothing is done to change that. Furthermore, shifting livestock species from grazers to browsers can mitigate the long-term effects of ruminant livestock population pressure on rangelands. In general, more research should be conducted to fill the current knowledge gap by determining the effects of trends in non-climatic factors, such as fire regime trends and land use dynamics, on range conditions in the rangelands of southern Ethiopia. This is critical for understanding how non-climatic factors exacerbated range condition deterioration in southern Ethiopian rangelands.

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